

# Reconstruction of primary vertices in $pp$ collisions at energies of 900 GeV and 7 TeV with the ATLAS detector

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The Large Hadron Collider (LHC) of the European Organisation for Nuclear Research (CERN) started its operation in Autumn of 2009. The initial run at a centre-of-mass energy of 900 GeV, has been followed by the on-going run at the energy of 7 TeV.

While initially the probability of several proton-proton collisions to happen within the same bunch-crossing was approximately  $10^{-5}$ , the level of the pile-up grows steadily with better focusing and squeezing of the LHC beams at collision point.

Presented in this contribution is the performance of the primary vertex reconstruction algorithms used for analysis of the first collisions at the LHC. Different approaches used for the reconstruction of primary vertices in 900 GeV and 7 TeV collisions are presented. The efficiencies of the primary vertex reconstruction used for the first physics analyses of ATLAS are shown. The resolutions on positions of the reconstructed primary vertices are investigated by studying the distributions of pulls of distance between artificially created half-vertices. Implications of the ATLAS performance with respect to primary vertex reconstruction for the on-going and future physics analyses are discussed.

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# 1 ATLAS Inner Detector

The ATLAS Detector [1] is a multi-purpose particle detector in operation at the LHC at CERN. The aim of the ATLAS experiment is to study  $pp$  collisions at energies up to 14 TeV. The detector is composed of several sub-detectors designed to study a variety of physics processes. For the reconstruction of vertices, the Inner Detector is of most importance. The Inner Detector is made up of the high-resolution semiconductor pixel and silicon microstrip (SCT) detectors and, at higher radii with respect to the interaction point, of the straw-tube tracking detectors (TRT). The entire setup is contained inside the superconducting solenoidal magnet, producing a field of 2 T.

The Pixel detector consists of 3 barrel layers, and 3 end-cap disks either side of the interaction point. The design resolution in  $R\phi$  and  $Z$  are of  $10\ \mu\text{m}$  and  $115\ \mu\text{m}$  respectively. The Semiconductor Tracker (SCT) consist of 4 double-sided barrel layers, and 9 end-cap discs at each side of the interaction point, providing a resolution of  $17\ \mu\text{m}$  and  $580\ \mu\text{m}$  in  $R\phi$  and  $Z$  respectively. The Transition Radiation Tracker is composed of 73 layers of straw tube chambers in the barrel and 80 layers in each end-cap providing  $R\phi$  resolution of about  $130\ \mu\text{m}$ . In summary, the Inner Detector provides around 3 Pixel, 8 SCT and 30 TRT measurements per charged track. A detailed description of the Inner Detector and of its expected performance can be found in [1].

## 2 Primary vertex reconstruction at 900 GeV

During the first run of the LHC, the probability of  $pp$  collisions to pile-up in the same bunch-crossing was estimated to be  $10^{-5}$ . Consequently, the primary vertex finder was configured to reconstruct exactly one primary vertex at each bunch-crossing. The tracks for the vertex reconstruction were pre-selected using the following criteria: measured transverse momentum  $p_T > 150\ \text{MeV}$ ; transverse impact parameter with respect to the beam position  $|d_0| < 4\ \text{mm}$ ; errors on measured transverse and longitudinal impact parameters:  $\sigma(d_0) < 0.9\ \text{mm}$  and  $\sigma(z_0) < 10\ \text{mm}$  respectively; at least 4 SCT hits; each track has at least 6 hits in silicon detectors and at least 1 Pixel hit.

A dedicated Billoir-like [2] fitter was used to fit the vertices. While the beam-spot information was used for the pre-selection, the beam-spot constraint was not applied during the fit. The tracks least compatible with the vertex estimate are removed one by one, starting from the highest  $\chi^2$  contribution. The process is repeated until no tracks incompatible with the current vertex estimate is left.

## 2.1 Analysis of charged particle multiplicities at 900 GeV

The measurement of the charged particle multiplicities at 900 GeV was the first ATLAS analysis based on the collision data. The details of the analysis can be found in [3]. The final measured distributions were corrected for the vertex reconstruction efficiency which was measured with respect to the Level-1 Minimum Bias Trigger Scintillators [3]. The efficiency was measured as a function of the number of primary charged tracks selected for the final analysis. The impact parameter cuts with respect to the primary vertex were replaced by the cuts with respect to the beam-spot position. The only identified source of systematic errors was found to be due to the beam background. Shown in Fig. 1 (left) is the efficiency of the primary vertex reconstruction as a function of number of tracks selected for the analysis. It can be noted that

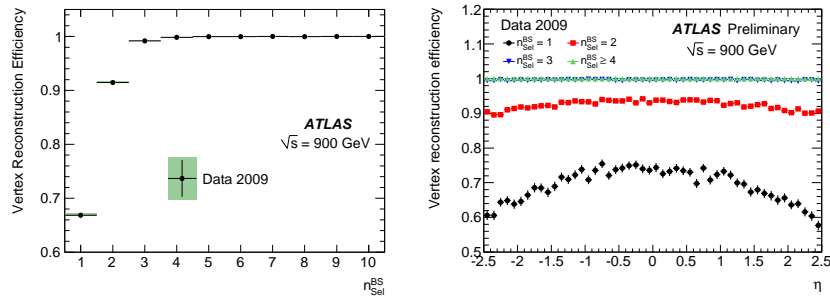


Figure 1: Efficiency of the vertex reconstruction as a function of the number of tracks selected for the analysis at 900 GeV (left). Efficiency of the vertex reconstruction for one, two and three selected tracks as a function of the pseudorapidity  $\eta$  (right).

the efficiency of 100% is reached already with four selected tracks. The inefficiencies for fewer than four can be explained by the cuts imposed on the quality of the reconstructed vertices: only vertices with three and more fitted tracks are accepted for the analysis. Shown in Fig. 1 (right) is the efficiency of the vertex reconstruction for one, two and three selected tracks as a function of the pseudorapidity  $\eta$ . An  $\eta$ -dependency of the efficiency was observed for the case of one selected track and was corrected for in the analysis.

## 3 Primary vertex reconstruction at 7 TeV

For the first data collected at 7 TeV, the amount of the pile-up was estimated as  $10^{-3}$ , which was no longer negligible. A new reconstruction strategy, based on the iterative vertex finder and adaptive vertex fitter [4] was used. The transverse momentum requirement for charged particle tracks was lowered to  $p_T > 100$  MeV.

First, exactly one vertex is fitted from all the pre-selected tracks. Then, tracks incompatible by more than  $7\sigma$  with this initial estimate are used to seed and reconstruct a new vertex candidate. This process is repeated until all available tracks are used or no new vertex seed can be created. The beam-spot information was used to constrain the vertex fit. The pile-up events were identified as triggered bunch-crossings where at least one additional primary vertex with at least 4 fitted tracks is reconstructed.

### 3.1 Analysis of charged particle multiplicities at 7 TeV

Shown in Fig. 2 (left) is the efficiency of the primary vertex reconstruction as a function of the number of tracks selected for the analysis of charged particle multiplicities at 7 TeV [5]. It can be noted that starting from three tracks, the efficiency reaches

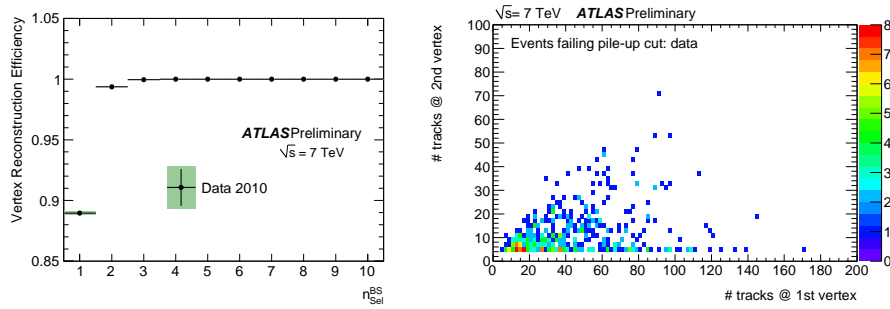


Figure 2: Efficiency of the vertex reconstruction as a function of the number of tracks selected for the analysis at 7 TeV (left). Number of tracks fitted to the second vertex as a function of number of tracks fitted to the first vertex for the events where more than one primary vertex was reconstructed (right).

about 100%. Comparing to the analysis at 900 GeV, smaller inefficiencies for low numbers of tracks are observed. This can be explained by higher track multiplicities in 7 TeV collisions and lower  $p_T$  threshold selected for this analysis. In addition, only the vertices with two and more fitted tracks were selected for this analysis. The efficiency was calculated only for the events where no pile-up was identified. The corresponding systematic uncertainty was found to be tiny.

Shown in Fig. 2 (right) is the number of tracks fitted to the second vertex as a function of number of tracks fitted to the first vertex for the events where more than one primary vertex was reconstructed. It can be noted that in a fraction of the events, the second primary vertex is produced. This may happen because the primary vertex has been split by the reconstruction algorithm or because of the misidentification of secondary vertices. The majority of such events are removed from consideration by applying the 4-track requirement mentioned above. The corresponding systematic effects are carefully evaluated and accounted for.

## 4 Primary vertex resolutions at 7 TeV

The resolutions on the positions of reconstructed primary vertices were calculated by correcting the reconstructed primary vertex errors by corresponding scale factors. Sets of tracks participating in the primary vertex reconstruction were randomly split in halves and corresponding pairs of vertices were reconstructed for each event. Gaussian fits were made to the distributions of distance pulls between split vertices. The scale factors were defined as the standard deviations of these fits. The measurement of the primary vertex position resolution is discussed in detail in [6].

Shown in Fig. 3 are the measured resolutions of the  $X$  and  $Z$  coordinates of reconstructed primary vertices as a function of the total number of tracks fitted to a vertex. It can be observed that the position resolutions reach the values of about  $30\text{ }\mu\text{m}$  in  $X$  and  $50\text{ }\mu\text{m}$  in  $Z$  for more than 60 fitted tracks. These values match the expectations for the 7 TeV minimum bias collisions with the  $p_T$  threshold of 100 MeV.

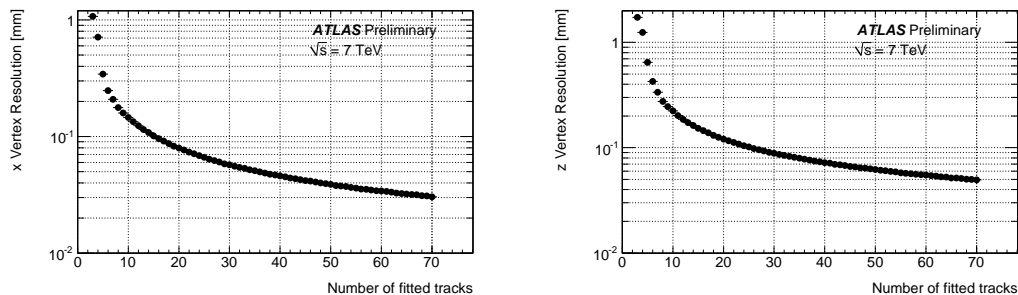


Figure 3: Resolutions of the  $X$  and  $Z$  coordinates of reconstructed primary vertices as a function of a total number of tracks fitted to a vertex.

## 5 Conclusions

The ATLAS experiment at the LHC has started to take data in the Autumn of 2009. Different strategies for the reconstruction of primary vertices were applied during the 900 GeV and 7 TeV runs of the LHC. Reconstruction efficiencies close to 100% are achieved in both cases. For the 7 TeV run, the coordinate resolutions of primary vertices reach  $30\text{ }\mu\text{m}$  and  $50\text{ }\mu\text{m}$  in planes transverse and longitudinal to the beam axis respectively for high multiplicity minimum bias events.

## References

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